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INSIGHTS ON INFORMATION ABSORPTION AND TRANSMISSION RATES IN C^2I SETTINGS

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for

Battlefield Information Systems Technical Area

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Recent advances in automatic data processing (ADP) greatly enhance the value of automated support to Army operations, yet this does not eliminate the importance of the human role in operations. As an example, in C^2I settings soldiers transmit and receive messages via computer, and these computers offer great potential for information transmission, storage, and computation, but the high volumes of information involved must still be interpreted by a person for them to be useful.

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In designing automated systems, it is therefore necessary to understand the user's needs and limitations. Systems developers have become more concerned with the amount and rate of incoming information which users can successfully comprehend. This paper addresses these concerns as a response to specific inquiries regarding the amount of incoming information which individuals can assimilate during a soldier-machine interface. The research note shows that the information absorption rate varies widely depending on factors internal and external to the individual involved. The impact of the amount and rate of incoming information on user performance is outlined by integrating the relevant psychological research literature on information processing, using a military application for the example.

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EXECUTIVE SUMMARY

As the Army's information and data flow requirements become more complex in areas such as all-source intelligence analysis, tactical fire control, and maneuver control, it has become crucial to understand exactly the user's needs and limitations. In designing automated systems, system developers have become more concerned with the amount and rate of incoming information which users can successfully comprehend. This research note addresses those concerns as a response to specific inquiries regarding the rate of incoming information which individuals can assimilate in a soldier-machine interface context. It is shown that the information absorption rate varies widely depending on factors internal and external to the individual. The impact of the amount and rate of incoming information on user performance is outlined by integrating the relevant psychological research literature on information processing using a military example application.

INSIGHTS ON INFORMATION ABSORPTION AND

TRANSMISSION RATES IN C^2I SETTINGS

Beverly G. Knapp & Carol A. Tolbert

Officer Smith is sitting at a control station in the tactical operations center, Division X. Teletype messages regarding unit location, status, crews and fire power are coming in at an average rate of two per minute. Consider the following example:

Alpha report as of 221800 Jul

APB718793YCYDPB744733

Translates to: Alpha report as of 221800 Jul:

A-1-22V (known) is located at PB718793 and has his basic load of ammunition between 50-75%.

B-1-22V (known) is still located at the last reported position and his basic load is in excess of 75%.

C-1-22C (known) is at the same location but his basic load is between 50 and 75%.

D-1-22C (known) has changed his location to PB744733 and his basic load is greater than 75% (messages are decoded using a matrix decoding scheme, from Corps Information Flow Study, 1978).

The soldier's task is to decode the incoming line of type and produce situation reports every four hours in a format appropriate to supply the commander

with knowledge of those "critical things which allow him (or her) to influence the battle in a timely, responsive manner" (Corps Information Flow Study, 1978).

A critical question is at once raised relating to the successful accomplishment of the task: is the rate of incoming messages too fast or too slow for optimal performance and accomplishment of the stated mission? The answer clearly depends on a variety of factors impinging on the soldier as transmission occurs, information is decoded and processed, and reports are prepared.

Factors Influencing Information Absorption

The types of factors affecting information absorption and processing are best understood by conceptualizing the sample soldier's task as an example of a typical information processing system, of which the soldier is one component. Figure 1 portrays information flow from inception to output in such a system:

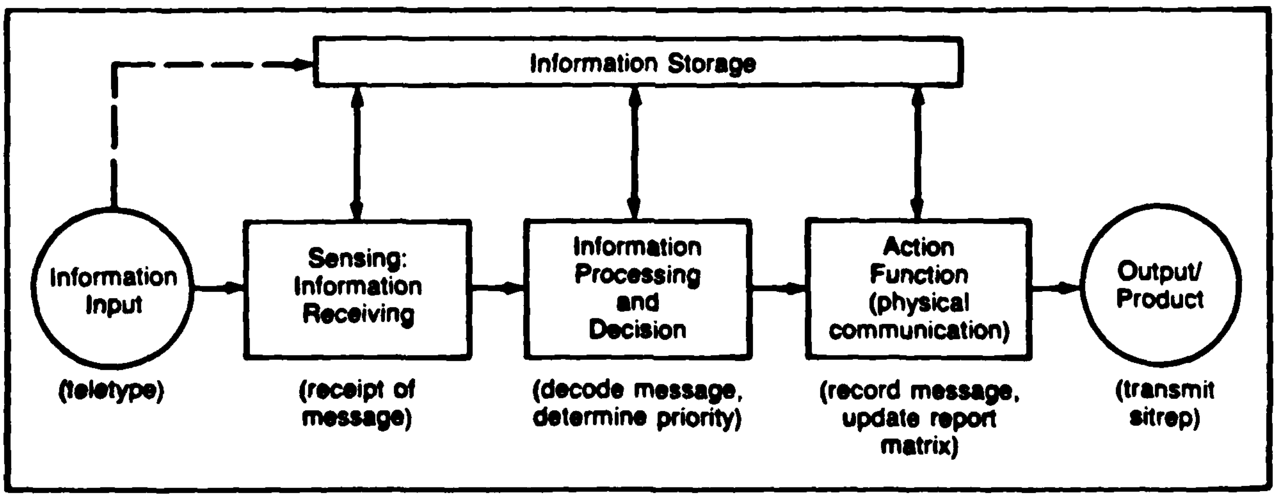

Figure 1. Typical Information Flow Functions in a generic communication system
adapted from E.J. McCormick Human Factors Engineering New York: McGraw-Hill, 1970. with permission.

The time from input to output is always influenced by how the information is handled along the line. Three categories of factors or variables are important in this regard:

1. System factors
2. User factors
3. Task variability as influenced by 1 and 2.

System factors. System factors include the mechanical aspects of the input/output devices, the physical layout of the control station, and generally how the message is presented and is to be transmitted. Issues of interest are:

. is the message presented verbally or symbolically, visually or auditorily

. how is the message formatted or coded

. how much control does the receiver have over the manner of message display and rate of influx

. how discriminable is the message from other ambient and environmental stimuli

. is the hardware easy to work with (i.e., user acceptable)

. are reporting and/or updating requirements easy to work with and produce.

User factors. User factors involve the vast array of qualities that constitute the human link in the system. These include experience, training, cognitive style, motivation, internal and external stressors, etc. Issues of importance include:

. how extensive is the soldier's training and experience in working with the message codes

. are there sufficient incentives to produce timely and accurate reports

. is the soldier fatigued, under personal stress, physically and/or mentally alert.

Task factors. Task factors are those elements which define the nature of the task itself. One of the most critical factors is the amount of incoming information per unit of time. Research indicates that whether the task is perceived as easy or difficult depends on this and other factors, such as required physical exertion and amount of time available to complete the task (Moray, 1982). When a large quantity of incoming information is presented on the terminal display, whether it is presented simultaneously or sequentially affects the user in different ways. If it is presented all at once, user performance deteriorates due to the great volume of visual information (Regal & Knapp, 1984).

If incoming information is presented sequentially, however, the nature of the task is changed. For example, in the sample message transcription task, effective performance may proceed indefinitely if the task were simply to decode and post incoming data. However, this is almost never the case. As certain messages will have a greater import than others, they will necessitate other kinds of actions than mere postings. A decision-making process must ensue, other actions must be taken and then succeeding messages become part of a queue. This introduces an element of stress into the information flow system. The soldier is no longer free to maintain the routine pace established, but must deal with priority items or other imposed demands. Thus, the simple transcription task never exists in isolation, continuing indefinitely,

but is always subject to modification and interference due to the various user and system factors (as per examples cited above) which continuously change its nature.

Considering the effects of the interplay of user and system factors on the information flow process, the rate at which information is absorbed will then be dependent upon what factors are operating at any given time. To illustrate this system, figure 2 represents a modification of the information flow process cited in figure 1, by including the influence of impinging user/system factors in a time-based model.

Note the time line on the left and the user/system factors on the right. This portrayal demonstrates that the time from t_o (input of message) to time t_5 (transmission of sitrep) is roughly 30 seconds (hypothetical estimation for the purposes of example). However, the influences from the user/system factors in the right column can subject the time line of subtasks to perturbation and delays. The maintenance of the consistent 30-second time cycle for message processing will only occur if there is no perturbation to the basic flow. When a user/system factor has direct bearing on a subtask, the result will be to either speed up or delay information processing and product output.

The system depicted in figure 2 has been studied extensively. In fact, a similar notion has recently been incorporated into a model of human-computer interaction. The model, which is more fully outlined in the Appendix section of this paper, entitled "Technical Background", has proved to be a useful method of studying and understanding the human-computer interaction.

Time/ seconds	Information Flow by Subtask		Typical User-System Factors Impinging upon Task Performance
t_0	Input: message imprinting on TTY terminal	USER	• alertness • previous message handling • previous task loading
		SYSTEM	• terminal characteristics • hardware maintenance status
t_1	Sensing: receipt of information/ officer detects message	USER	• attentional capacity • visual acuity
		SYSTEM	• alerting mechanism • ambient conditions: • luminence level, legibility
t_2	Information Processing: decoding, translating/trans-scribing written text	USER	• training • experience • skill level
		SYSTEM	• coding strategies • interactive features • acceptability of features
t_3	Decision Making: determine message priority/formulate response	USER	• training • experience • cognitive strategies • net cognitive load
		SYSTEM	• time pressure • urgency-priority
t_4	Take Action: perform maneuver/update sitrep matrix/ phone call, etc.	USER	• skill level • psychomotor capabilities
		SYSTEM	• access to communication channels • feedback from environment/superiors - subordinates
t_5	Output: transmission of sitrep through chain	USER	• familiarity with transmission protocol • readiness
30 seconds (hypothetical)		SYSTEM	• type of transmission channels • protocol for transmission • readiness of transmission channels
to new message entry			

Figure 2. User-system factors influencing rate of information flow in a time-based system for a simple transcription task.

It is within the above context that the rate of information absorption is best considered. To say that a human operator may absorb "2 Hz per second" is simply to use a term from acoustics which refers to frequency of occurrence in cycles per second. In this case a "cycle" is an undisturbed occasion of message input to report output, with smooth accomplishment of intervening subtasks. The fact that this almost never happens affects how accurately the rate of information absorption can be determined. In the present example, an incoming rate of two messages per minute may be optimal on one occasion, too slow in another instance and overwhelmingly fast in a following instance. A well-trained, experienced soldier who is not fatigued or imposed upon with other demands may be able to allow several minutes worth of messages to form a queue. With a glance, the message series may then be perused, a sitrep matrix updated, leaving time to spare. A soldier who is just learning and faces a command directive to provide immediate, current status information to an intermediary, will be overwhelmed by the influx of messages while trying to respond to the additional tasks. What is automatic and even routine to one controller is going to be consciously difficult for another.

Let us now suppose that in addition to receiving and interpreting incoming messages, the soldier must also actively reply to the incoming information. In other words, he must formulate a reply and find the correct means of sending it. His specific task is to decide how to respond and to type the response into the terminal. The two critical issues at this point are (1) ensuring that the correct reply is obtained and (2) ensuring that the reply is correctly typed in. Again, many factors influence the rate and accuracy with which outgoing responses are transmitted.

Factors Influencing Information Transmission

In order to actively reply to an incoming message, it must be decoded and processed, as explained earlier. Thus, the transmission of information becomes the next step in the human-computer interaction. Because of the sequential relationship among the steps in processing incoming information, the factors which influenced information absorption rate will also influence the information transmission rate. Consequently, the discussion which accompanied figures 1 and 2 also applies to information transmission. Specifically, system factors, user factors, and task variability affect the rate and accuracy of information transmission.

System factors include those presented in the previous section. In addition, however, they also include a number of additional system specifications. These include, for instance, the location of the keys on the keyboard, and the separate aspects of the terminal display which, in unison, yield the display of the user's response. Research has shown, for example, that the typing rate of expert typists on a conventional Sholes (QWERTY) keyboard was found to be 8% faster than on an alphabetic keyboard (Underwood & Schulz, 1960). Another study (Barmack & Sinaiko, 1966) found that performance was improved when the user was provided with feedback and when the lag between his response and the display was reduced. Taken together, these studies demonstrate the critical importance of carefully considering human variables when designing a system and evaluating user performance.

Of the previously mentioned user factors, the most important one in information transmission is user experience. Evidence has long supported the notion that the time to perform a task decreases with practice (Snoddy, 1926). An experienced typist inputs information much faster than does a novice.

However, many other factors contribute to performance other than the user's level of experience. One of the more pertinent ones is the role of attention in transmitting information. Research has shown (Haber, 1932; Sipowicz & Baker, 1961) that people have relatively short attention spans, that they get bored with repetitive tasks, and that their past experience colors their perceptions. This results in decreased performance accuracy. Consequently, computer tasks should be designed to maintain the user's vigilance.

Task factors were also described in the previous section. Probably the most relevant one in information transmission is the exact amount of time allotted for the task. It is especially critical in information transmission because it affects both the accuracy of the outgoing message and the user's perception of task difficulty. Studies have shown that a speed-accuracy trade-off operates in many tasks, and that users perceive the task as more difficult as its allotted time decreases (Darjanian & Sheridan, 1980).

Another time variable is when the user is presented with numerous messages to be transmitted within a very short period of time. In our example, this situation prevails if the soldier is required to send multiple responses in a brief period of time. He must decide the order of priority of outgoing messages and then send them in that order as quickly as possible. The order of outgoing messages thus forms a queue. (The notion of a queue is discussed in the Appendix.)

The complex interplay of user, system, and task factors is also evident in information transmission tasks. The rate of accuracy of transmitted information is contingent upon a number of simultaneous variables, as shown in figure 2. The actual information transmission occurs in the last two steps of the figure. Again, note that it is tempting and commonplace to refer to an

information transmitter's task as simply "sending messages." Holding this simplistic view, however, one cannot account for why one soldier transmits information quicker and more accurately than another. To understand and adequately evaluate the situation, it is imperative to be aware of the various user/system/task factors. Rather than conclude that the second soldier is less competent than the first, the two situations should be compared and contrasted in light of user/system/task factors. For example, it may be found that: the second soldier's attention span is shorter than the first one's, or that the second soldier's psychomotor capabilities are not as coordinated as the first one's, or that the time allotted for transmission is too short for the second soldier to adequately perform, or that the terminal being used by the second soldier is internally set to operate at a slower rate. The first two possibilities are user factors, the third is a task factor, and the fourth is a system factor. Yet any one or more than one of these possibilities may be operating at any given time. Once the problem source has been found, it is then possible to take remedial action.

The transcription task described above is an example of a very simplistic task in which incoming messages are automatically typed on a printer/terminal and the soldier works directly with the printed page to decode, process, and respond. In a computer-based command center, however, incoming G2 information typically enters an automatic memory storage unit first. This capability potentially changes the task scenario dramatically. Note the block labelled "information storage" in figure 1, the simple communication system. This descriptor can apply to the hardware component responsible for accumulating messages and allowing an operator to access and reply to these in a controlled way. Some prior programming may also allow transcribing, aggregating, and

recording functions to be performed by the machine. In this situation, the soldier may be viewing only summaries of many reports, or records of change over time, or be alerted to critical changes only if they meet certain pre-established criteria. In this case, there would not necessarily be a decision regarding the order in which to transmit messages; the storage unit would handle this.

However, even with this task transformation, the issue of information absorption and transmission remains. New questions are raised regarding the use and access of stored information, the ease with which one responds to automatically highlighted critical elements, and how the order of entering information is determined. Regardless, information must still be received and processed, decisions made and actions taken, all in a time-sensitive manner. Questions of information format and display, user training and experience, and determination of desired outputs will still pertain to the rate of information absorption and transmission.

Summary and Conclusions

The foregoing presentation of a sample task has illustrated the impact of user and system factors as impinging upon the rate of flow of information in the accomplishment of the task. Emphasis was placed on showing examples of the knowledge base available relating to the nature of human processing. While there is considerable literature available to offer guidance in the design of system elements (e.g., McCormick, 1970; Van Cott & Kinkade, 1972), the human is viewed as the critical element which determines rate of information flow in task performance. This is because the effective design of system elements is really based on an understanding of human processing capabilities

and limitations. In any dynamic system involving objects and humans configured together, the human is really a system within the larger total network. Figure 3 illustrates this simple concept.

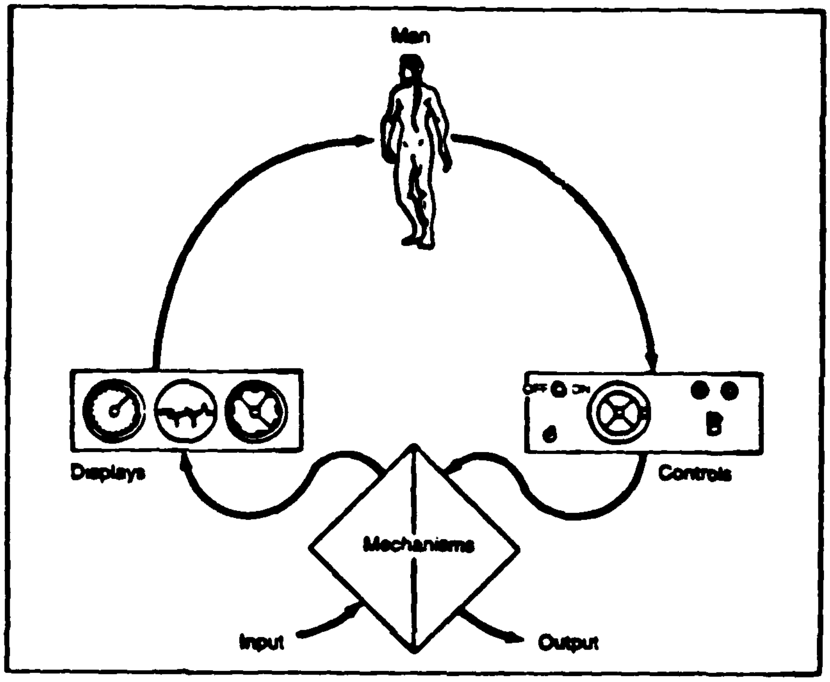

Figure 3. The human operator is represented an an organic data-transmission/information-processing link in input-throughput-output communication cycling of information flow

from E.J. McCormick Human Factors Engineering New York: McGraw-Hill, 1970. reprinted with permission.

Given the above premise stressing the importance of comprehending the nature of human processing, rate of information absorption and transmission by the human may be determined by applying what is known to specific task contexts. Consider the command and control setting as an example of how the process of knowledge application and task specification may lead to determining information absorption and transmission rates. Referring back to figure 2, there is a flowchart of subtasks for a particular task from start to

finish. At each time (t_o, t_1,... t_5) the relevant user/system factors are listed extensively. These specify the exact parameters of the environment, hardware, message format, etc. For each subtask, an estimate could be given for the time required to execute it. The rate of information absorption and transmission is then simply the cumulative time from t_o to t_5. This is strictly an analytical process, using given task, user, and system specifications and applying general estimates of processing time from the knowledge base. The exercise does not stop here, though. It is likely that the cumulative time estimates will not be accurate, either because some element has not been clearly specified, or a knowledge gap does not allow precise determination of a time. However, the preliminary work for test and evaluation to determine precise times has already been accomplished by the analytical process. Now it remains only to select methodological techniques from the knowledge base to test specific subtask skills in an experimental situation. Since the task, scenario, and user have already been specified, testing is a relatively straightforward matter. With the trend toward computer reception of a highly speeded influx of information from a variety of sensors and other G2 sources, the command and control posts will have access to large amounts of time-sensitive inputs. It is important that the rate at which humans can process and absorb these data be assessed, so that the benefits of the automated collection, storage, and display components will not be lost. The preceding description is one such assessment technique.

Conclusion

This report was in response to a specific request from the Army system development community to ascertain whether specific data are available for how much information an individual can absorb per unit time. It has shown

that in fact, no specific human data processing rates are available because each situation is accompanied by internal and external factors unique to the individual and system components being considered. A simple task was developed and described, showing how a specific data processing rate might be computed, given that factors impacting the task under consideration could be clearly specified. Also included is an appendix providing more detailed background of the behavioral science literature on information processing, for readers who wish to pursue technologies specific to their own system application.

Appendix: Technical Background in Human Information Processing

This section is a detailed discussion of psychological concepts and of illustrative studies conducted in the area of information processing. What was illustrated in the body of the report by means of the message transcription task is that user and system factors determine the rate of information flow in a communication sequence (input-processing-output). Absorption rate is a function of user reception of information at any given point in the cycle; transmission rate is a function of information acquisition at a particular time.

A technical knowledge base has been developed in the area of cognitive psychology which addresses the processing capabilities of individuals as they acquire, modify, manipulate, store, and use information. Models have been constructed (see a summary diagram, figure 4) to conceptualize human processing as information proceeds through various internal structures or levels (e.g., Neisser, 1967; Craik & Lockhart, 1972; Norman, 1980). Research findings lend insight into how well and how quickly information is represented and transferred in a given processing activity. In specified tasks, human performance has been measured to record speed and accuracy in identifying targets, recognizing objects, comprehending texts, etc. Each of these is contingent upon the various formats of the information and internal/external conditions in that situation. While some general principles are known regarding processing capabilities, no general rates of absorbing or transmitting information may be developed until applied to specific tasks with their attendant parameters.

In the case example of message transcription, the following questions would need to be answered before pertinent knowledge could be applied:

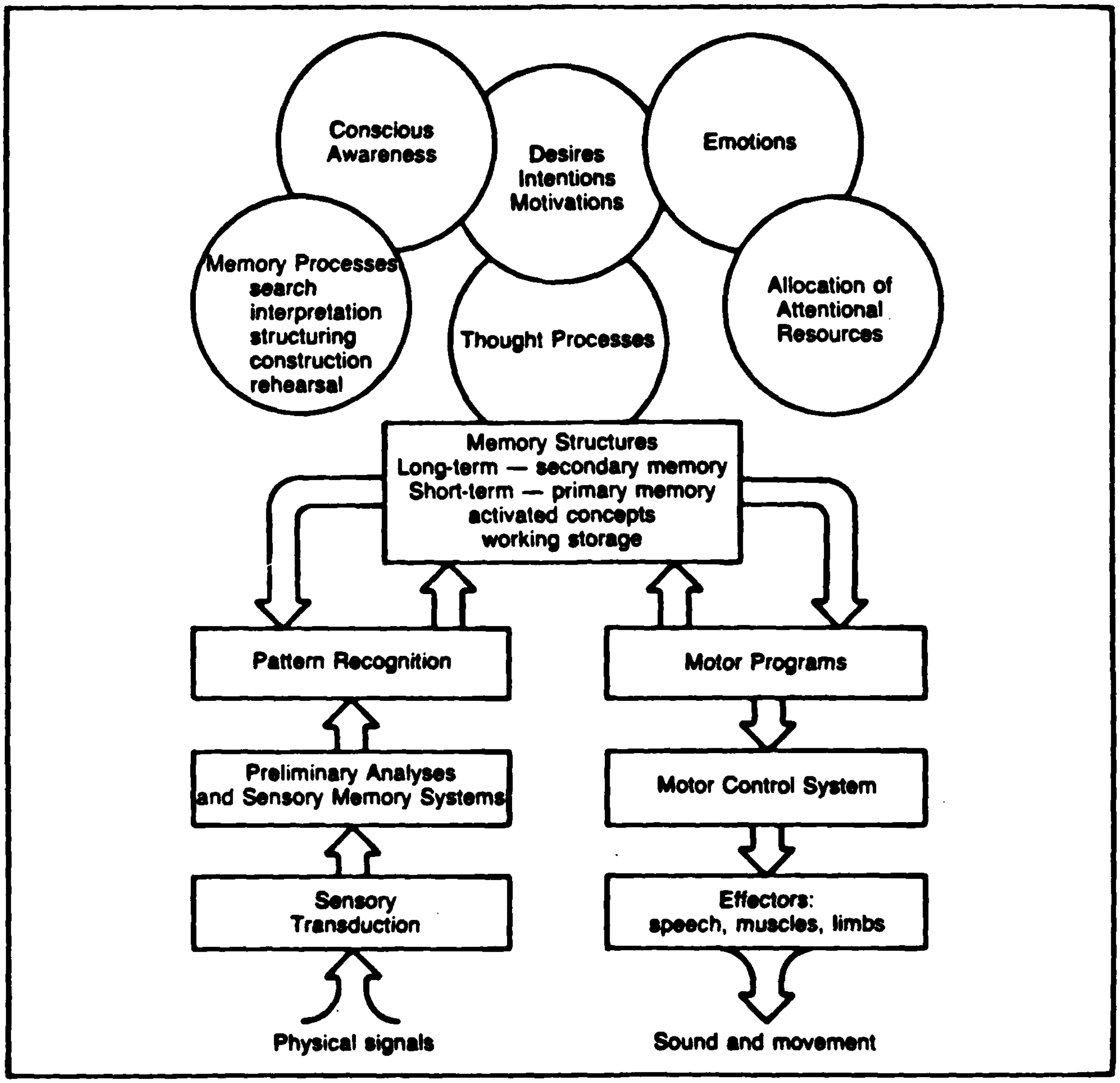

Figure 4. A modern version of the conventional flow chart of the human information processing system. The basic components are a series of processing mechanisms that take in information about the environment, perform general central processing operations, and control motor output. The central processing is complex, with various sources of knowledge interacting with one another, controlled by an as-yet little understood processing structure which allows for some simultaneous operation, self awareness, consciousness of some of the processes. The stuff in the central part of the figure is sufficiently vague as to allow for a large number of interpretations of its nature

from D.A. Norman "Twelve Issues For Cognitive Science" in Cognitive Science. 1980, 4 (1) pp. 1-32 reprinted with permission of Ablex Publishing Corporation, Norwood, N.J.

(1) who is the user (MOS, skill level)

(2) what is the mode of incoming information (visual/auditory; verbal/ symbolic; printers, CRTs, etc.)

(3) what is the nature of the information extraction required (i.e., target detection; pattern recognition; verbal comprehension; decoding; decision making, etc.)

(4) What is the desired outcome of the task (i.e., target identification and reporting; report preparation and transmission; situational analysis; initiate engagements; command decision).

Once a given task scenario has been specified, information rate and ease of information handling can be evaluated and tested by an application of current knowledge and empirical methodology.

Sensing and detecting. As evidenced in figure 4, sensors in the human nervous system feed a steady stream of information about the environment to some central processing structures where that information is analyzed, interpreted, and fed to a response system (Norman, 1980). A common task is to detect the presence or location of particular signals in a visual or auditory field. In this task, the structure or characteristics of the signals, the field, and their interactions have received extensive study. For example, in visual perception, heterogeneity of the field in terms of hue, form, size, and brightness is a significant factor in search time. Search time in general was found to increase with increasing heterogeneity of the field (Eriksen, 1953). Besides heterogeneity on various dimensions, a display or perceptual field can vary in terms of other characteristics. One is the amount of information it contains. A field may be saturated with signals or the signals may be few but

widely scattered. Perceptually this variable is known as the "figure-to-ground" ratio, or "signal-to-noise ratio" (Eriksen, 1955). The speed with which an observer can detect and identify specified signals will be affected by this ratio. Research findings indicate that (a) as the number of signals or objects in a field is increased, the time required for location of a constant number of specific signals also increased; (b) when the field was partitioned or formatted in some way, search time decreased; (c) if the target signal complexity is enhanced, detection will be facilitated; and (d) if the noise background complexity is enhanced (increased), a progressive decrement in target recognition will occur (French, 1954).

In a study by Banks and Prinzmetal (1976), using a detection paradigm of signal-to-noise, the hypothesis entertained was that the mutual interference between target and noise items is increased when they are perceptually clustered together in the same group and decreased when they are perceptually clustered in different groups. A single generalization characterizes all of the effects of organization on processing: the more the target is perceptually grouped with noise, the more it is interfered with by the noise. If the noise and target come in on different "channels," they will interfere less with each other. The separation of signals from noise implies some sort of elementary processing or grouping operations in the sensory/perceptual system, even before it reaches a central processing network. These findings and others similar to them (e.g. Neisser, 1976; Reicher, 1969) indicate the importance of configuring the incoming targets or messages to be compatible with the preliminary perceptual processing exercised by sensory receptors.

Comprehending verbal messages. Criteria for the spatial arrangement of words on the printed page have been investigated for almost a century. Extensive research, reviewed by Tinker (1963), has evaluated such issues as vertical versus horizontal layouts and line widths for best reading performance. Cornog and Rose (1967) report some 140 studies that have examined the layout of alphanumeric text materials. These types of tasks have noted the interaction of these factors on reading speed or time on task for different sorts of displays, testing for or assuming equivalence of comprehension. Other studies (i.e., Levy-Schoen & O'Regan 1979; Rayner, 1978) have used eye movement measures of reading performance. It has been found that difficulty, discriminability, comprehensibility and related features of text processing reveal themselves through changes in frequency, duration, and location of eye fixations (Kolers et al., 1981).

Huchingson et al. (1981) found that message formatting was a critical variable in rate of message assimilation and comprehension. "Format" refers to the manner in which words are arrayed. Arrays of words tested included vertical alignments, compact arrangements, and "chunking" according to meaningful groups. In addition, some messages were presented in sequential fashion, that is, a series of discrete word or chunk presentations were shown over time to relay the entire message. Findings indicate that dividing messages into one word per sequence or vertically led to poorest comprehension. Chunk and chunk sequencing were the most satisfactory for message comprehension and recall.

Detecting and comprehending symbolic vs. word messages. The previous two sections have highlighted research areas in the perceptual identification and comprehension of targets of word messages. In some cases, comparisons have been made between the use of symbolic or pictographic elements and alphanumeric or verbal presentations of the same concepts, in order to determine speed and ease of discrimination. The premise in some of these studies was that a "picture was worth a thousand words" and could more easily depict a key concept or bit of information. The fact that a symbol is pictorial does not always guarantee its connection with its intended associate. Kolers (1969) has shown that information conveyed by a symbol will depend on a viewer's previous experience and knowledge, as well as specific training and expectancies. In general, though, the appropriate use of symbols has shown major advantages in being perceived more rapidly (Janda & Volk, 1934), more accurately (Walker, Nicolay, & Stearns, 1965), and at a greater distance (Dewar & Ells, 1974) than words. Reaction time to symbols may be shorter (Ells & Dewar, 1979), even under visual degradation. Symbol meanings can often be rapidly learned and accurately remembered (Walker et al., 1965), with minimal confusion among alternatives (Green & Pew, 1978).

Cognitive processing of information. Once information has been transduced by sensory receptors (visual, auditory, etc.), the incoming information is somehow matched and encoded by mechanisms or structures further along the cognitive system: Referring again to figure 4, the processes of pattern recognition of sensory stimuli are then followed by manipulations within various types of memory, which are in turn influenced by thought processes, emotions, attention, etc.

One of the most recent models to assimilate the information processing approach is called the Model Human Processor (Card, Moran, & Newell, 1983), depicted in figure 5. The model may be interpreted as a functional analog of the human components necessary to process incoming information. The components of the model work together to form three interacting subsystems: The perceptual system, the cognitive system, and the motor system. The perceptual system consists of an initial processor and of memories, the two main ones being the Visual Image Store and the Auditory Image Store. The cognitive system receives information from the sensory system and places it in Working Memory while previously stored information is retrieved from Long-Term Memory to aid in making a decision about the incoming information. The motor system actually carries out the decision in the form of a response.

To illustrate the model with an example, we return to the message transcription task. The soldier sees the message on the display. The visual image of the message enters the Perceptual Processor; next, it is temporarily stored in the Visual Image Store. At this time, previously stored information which is relevant to the message is recalled from Long-Term Memory. The Cognitive Processor uses the Visual Image Store information and the Long-Term Memory information as a data base of pertinent information to initiate the decision-making process. When a decision is reached, it is relegated to the Motor Processor, which executes the response. The soldier responds by typing the appropriate key(s).

The model incorporates a number of principles of operation, which are mathematical laws defining the parameters of performance. The principles of operation quantify the manner in which performance will be affected by numerous variables, many of which were presented earlier in this paper. It is

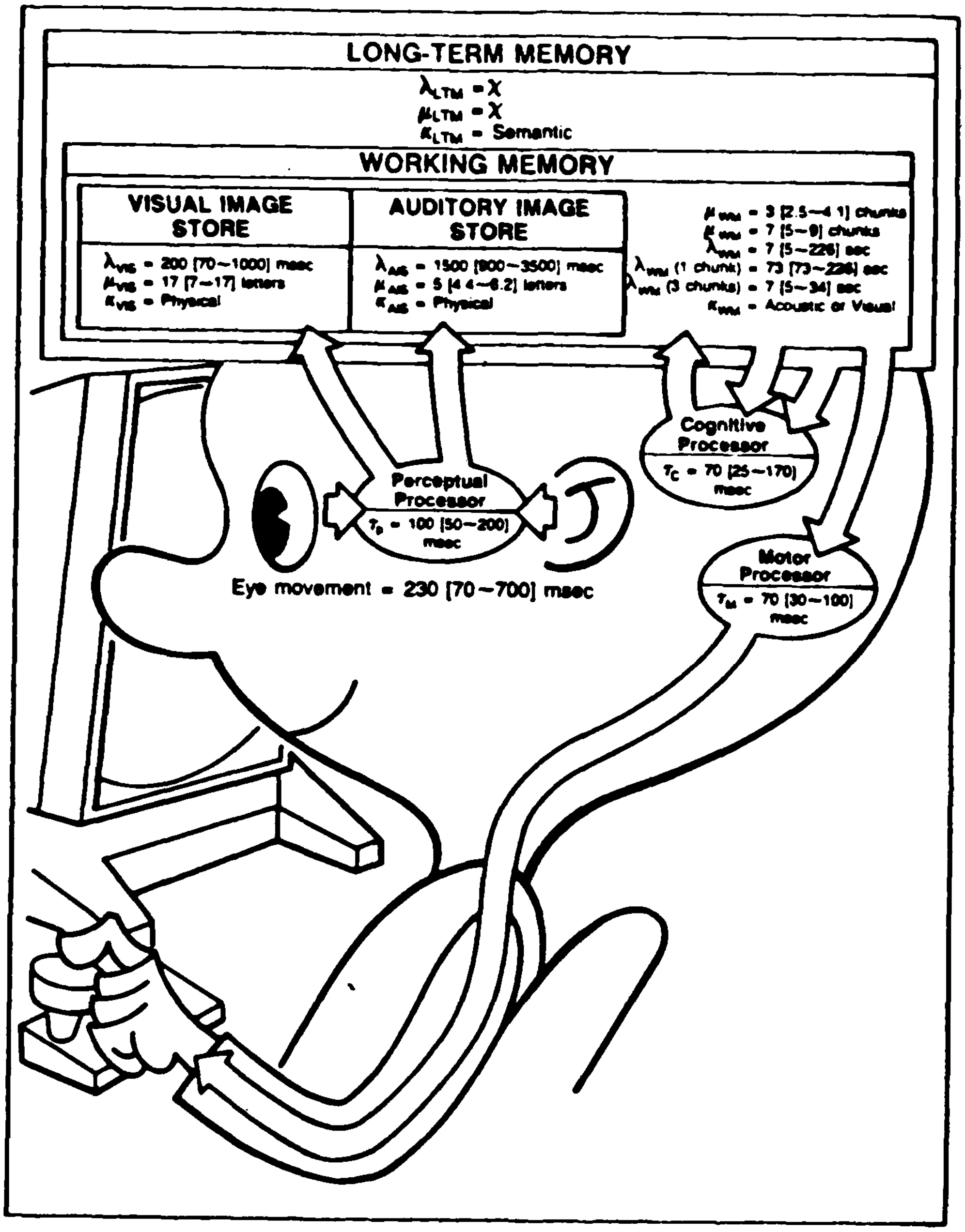

Figure 5. The Model Human Processor--memories and processors.

Sensory information flows into Working Memory through the Perceptual Processor. Working Memory consists of activated chunks in Long-Term Memory. The Motor Processor is set in motion through activation of chunks in Working Memory.

possible, for instance, to solve the following problem: "A user sits before a computer display terminal. Whenever any symbol appears, he is to press the space bar. What is the time between signal and response?" (p. 66). Many other realistic problems can be solved which allow us to make knowledgeable decisions regarding the effects of certain factors on user performance.

The model also offers a principle which takes into account varying amounts of incoming information. It is possible to estimate how each subsystem will respond to these differences, because the model specifies the storage capability of each of its components. In sum, the model is valuable because it is a framework in which the entire information-processing sequence can be conceptualized, and because it provides a method whereby practical problems can be solved.

Whether or not these memory structures and mechanisms are actual structures, or simply ways of conceptualizing levels of processing occurring for different stimuli, is the subject of some controversy (Craik & Lockhart, 1972; Baddeley, 1978). However, the idea is that the resulting information is relegated to central processing and thereby brought to "consciousness" for active labelling, that is, what we are immediately thinking about, working with, and may incite us to act. Most studies in this area have come from verbal learning investigations, confined to the use of verbal materials. It has been suggested that the processing occurring at this level has limits (e.g. Miller, 1956; Broadbent, 1958; Shiffrin, 1975) because it demands our attention, and therefore sensory information must either be filtered and ignored, or queued until attention may be devoted to it. Miller's article (1956) "The magical number seven $\pm$ two", was one of the first to create awareness of a limited capacity to retain and process sensory items. The principal

assumption of the limited-capacity view is that attention demanding (or cognitive processing) can be distinguished from another type of processing, automatic processing. An automatic process is one that can handle as much information as is presented--for example, ears automatically register sound waves whether one, two, three, or more sounds are presented. Although the sensory response to stimulation is automatic, at some point the system becomes unable to process all of its inputs because of limitations in its capacity. This is the point at which attention occurs.

Note that the point at which attention occurs will vary in different situations depending on rehearsal of subtasks, training, experience, incentives, etc. (Klatzky, 1980). An example will clarify this point. Consider what happens when you first learn to drive an automobile. The instructions you receive emphasize the actions and the mechanics; hold the steering this way, synchronize foot (for clutch) and hand (for gearshift) that way. As you progress, the point of view changes. Now you are turning the wheel, not moving your hands clockwise. Then you are turning the car, later you are entering that driveway. Eventually, as a truly expert driver, you drive to the bank, go shopping. The differences in qualitative feeling are vast. At the expert level, you are no longer "aware" or conscious of all the subsidiary operations that you perform: you look at the driveway, form the intention to enter, and the car responds. Driving the car becomes natural and subordinate to other attentional demands (Norman, 1980).

The processing of information in the military scenario will be much the same as developing a driving skill. Experienced soldiers will handle messages and generate responses in an almost automatic manner, except when critical, novel elements demand attention. Novice soldiers will be overwhelmed by

message processing, until their skills have become separable from the cognitive learning that must occur. The pressure of time and the rate at which information can be absorbed will be a function of the degree to which the assimilation of messages is an automatic process.

Development of cognitive decision-making skills. A final area of the knowledge base of information to be described is cognitive skill development, or decision making. In some cases, a soldier in command is involved in decision tasks that have high attentional demands, requiring the aggregation and assimilation of many information sources in order to derive plans of action. Studies in this area have examined such concepts as the cognitive management of information, and decision strategies to reduce "cognitive load" (cf. Kibler, Watson, & Kelly, 1978; Katter, Montgomery, & Thompson, 1979; Katter, Montgomery, & Thompson, 1979a; Phelps et al., 1980). The goal of these studies was to determine the most effective way to allocate attention, assess cognitive load, and develop strategies or aids to reduce the load (Donnell & Patterson, 1981). Once net cognitive load is beyond a given capacity, the human must either shed some of the load, or suffer a deterioration, if not a breakdown, in performance. With excessive load, the rate at which information can be absorbed and processed for effective decisions will be decreased. Several concepts have been proposed to counteract this, including selective attention techniques, task simplification, and task delegation (Donnell & Patterson, 1981). Careful attention to how information is presented, in terms of reports, displays, sensor updates, etc., will have a bearing on how easy it is to integrate information and thus produce effective, timely decisions.

Mentally loading a person has the effect of destabilizing the processes that use anticipation to regulate automatic processing and allow attention allocation for complex decision tasks. Hacker et al. (1978) state that properly coded knowledge of the task can save time by increasing the efficiency of processing, hence reducing cognitive load. Work in time stress and decision analysis has been based on certain mathematical principles and theory, and has been revealing regarding what factors interfere with and facilitate decision making. The study of time stress relates the problem of time to mental workload (Moray, 1982). Attempts have been made to measure the relationship between the two. Senders (1979) asserts that unless there is time stress in a task, there is by definition no mental load. The mathematical/conceptual framework for this work is queuing theory, which predicts "load" based on the probability that the human will be busy at the time a signal or message arrives. The overall conclusions indicate that difficulty of task execution (and thereby rate of processing) is a function of the need to generate lead time in task performance so as to keep up with incoming information. In a similar vein, statistical decision theory has been used to derive decision analysis techniques to reduce judgmental errors. Complex decisions are partitioned into more basic elements in order to allow subjective assessments of incoming chunks of information to be dealt with separately. Then a means is provided through formal, logical algorithms to arrive at a formal choice (Kibler, Watson, & Kelly, 1978).

These types of studies allow the explicit understanding of elements of the decision-making process, so that decision aids and effective training may be developed in applied situations where the rapid processing of large amounts

of information is required. In the intelligence area, for example, the analytic operations of intelligence analysts have received extensive study (Katter, Montgomery, & Thompson 1979, 1979a). Here an extensive cognitive model of the analyst was developed, based on a more general assessment of human information processing, and then relating it to the specific tasks of G2 analysts. This application resulted in the actual explication of cognitive tasks within analysis, and provided the basis for a field training circular to teach these tasks (INTACT, 1984) to new analysts.

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